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TRANSLATION

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On Angular Distribution of Ions of Alkali Elements, Diffused by the Surface of Metal

by

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To explain the mechanism of reaction of particles with surfaces of solid bodies of greater importance is the study of the angular distribution of secondary particles. Quite thoroughly was investigated the angular distribution of elastically and inelastically diffused electrons in relation to the energy of the falling electrons and the nature of scattering targets [1,2]. A number a reports has been published on the distribution of intensity and energy of diffused gaseous ions [3, 4, 5] and neutral atoms [6] on atoms and molecules. But angular distribution of secondary diffused ions, originating during the bombardment of metal surfaces with ions of alkali elements, has not been sufficiently investigated so far.

For the first time angular distribution of ions diffused from Pt-targets during bombardment with positive ions Li^+ and K^+ in the range of energies from 20-250 ev was investigated by G.Redd [7], who points toward the presence of a definite direction of maximum diffusion, coinciding with the direction of a mirror reflection from a flat surface. In the report is also mentioned an increase in energy of diffused ions with the rise in energy of primary ions.

R.Cerney [8] investigated the distribution of energy and intensity of scattered Li, K and Cs ions along the angles with red hot Pt-target.

The author states, that the energy of ions scattered at a certain angle rises with

an increase in angle of incidence from 20% of the energy of primary ions at normal incidence to 80% of energy of primary ions when approaching tangential incidence.

At a fixed angle of incidence the intensity is low in direction of the normal to the target, but rises unavoidably with an increase in reflection angle.

The intensity of scattered ions depends upon the energy of incident ions at given angles of incidence and reflection. The dependence curve in this case has a maximum (E_0 = 40 ev for Li^+, K^+, Cs^+ ions).

A.Langacre [9], who investigated angular distribution of energies and intensities of ions scattered during the bombardment of Ni with Li^+ ions, states, that the results of studying the nature of energy and intensity changes of scattered ions in dependence upon the angles of incidence and scattering within limits of experimental accuracy coincide with the data of the R.Cerney [5] report. A.Langacre discovered preferential scattering of ions in a wide cone, whereby the direction of the intensity maximum of scattered ions does not depend upon their angle of incidence. But he considers the relationship between the direction of maximum scattering and the direction of mirror reflection as casual.

R.Sawyer [10] investigated the scattering of Li^+ ions from the surface of Pt and Ni crystallites, deposited on tungsten plates. The author noticed two directions of maximum reflection. One [7,8] coincides with the direction of mirror reflection and does not depend upon the energy of the primary beam, the second one- detected between directions of the incident beam of ions and the normal to the surface. R.Sawyer, explaining the observed phenomenon, assumed the presence of a mirror reflection from the surface of Ni crystals.

Selliger R.and Sommermeyer K; [11] investigated the angular distribution of intensity of secondary diffused ions along the angles when a Pt-target was bombarded with K-ions. The authors revealed that the distribution of intensity of secondart scattered ions in the energy interval of up to 1000 ev is subject to the cosine law.

M.A.Yeremeyev and M.V.Zubchaninov [12] also investigated angular distribution of intensity of secondary particles in relation to φ an θ when bombarding a hot and cold Ta-target with K^+ ions in the zone of energies of 2-4 kev. The authors are placing special emphasis on the fact that near the direction of mirror reflection there is a tendency of maximum intensity of secondary scattered ions. They point out, that with a reduction in φ the intensity maximum of scattered ions is washed out entering the side of greater θ.

According to M.A.Yeremeyev and M.V.Zubchaninov at a sliding angle of incidence the reaction of ions, falling on the surface of the target, is not with individual atoms of the crystal lattice, but with certain surface elements. At the end they arrive at a conclusion, that the distribution of intensity of scattered ions by the angles is not subject to the cosine law.

Yu.A.Arifov and A.Kh.Ayukhanov investigated [13] the distribution of energies, maximum energy values and intensities of secondary ions in dependence upon φ and θ when bombarding a pure heated Ta-target with Na and Rb ions. Special attention was devoted to the purity of experimental conditions.

It was established, that maximum energy of scattered ions appears to be a synonymous function of the angle between the direction of the primary beam and the direction of flowing out (departure) of the scattered ion. These maximum energies coincide with the values, calculated in the assumption of an elastic collision of the primary ion with surface atoms of the target, determinable by expression

$$E = E_0 \frac{(m_1 - m_2)^2}{m_2^2 \left[\cos\beta + \sqrt{\left(\frac{m_1}{m_2}\right)^2 - \sin^2\beta} \right]^2}, \qquad (1)$$

where m_1 and m_2 are the respective masses of target atoms and of the bombarding primary ions. $\beta = \varphi + \theta$.

The number of secondary ions, departing in direction of the normal toward the surface of the target, does practically not depend upon the angle of incidence of primary ions. The number of secondary ions, scattering under various angles of departure,

deviates from the cosine law, and in first approximation can be described by a linear dependence.

In this way, if one group of authors [7, 8] maintains the presence of a mirror reflection of the ions from the surface, others [10, 11, 13] negate same. Certain researchers [9, 10] having detected a preferential tendency of scattering, do not combine same with mirror reflection. In one of the recent reports [11] points out that angular distribution of intensity of secondary ions is subject to the cosine law, while in other reports [12, 13] such a law (validity) is negated.

It should be mentioned, that in a majority of instances the distribution of energy and intensity of secondary ions by angles was measured in insufficiently pure (clean) vacuum and surface conditions using inertia instruments at low target temperatures. When investigations were made on high temperature targets no consideration was given to the phenomena of surface ionization and diffusion accompanying secondary emission, of ions penetrating into the target for $V_i \angle \varphi$, where V_i - potential of ion ionization; φ - function of target departure. The used ion beams in a majority of cases had in their composition neutral particles. That is why the experimental conditions of various researchers were of various nature, and their results could not supplement each other and were found to be contradicting.

It is evident, that to obtain an actual picture of angular distribution of intensities and energies of secondary ions upon the bombardment of metal surfaces with ions, these experiments must be carried out in much cleaner conditions from atomary clean surfaces and with the aid of methods, eliminating surface contamination in the process of measuring.

Arrangement of Experimental Installation and Measurement Method

The experiments were conducted in a glass vacuum instrument. The arrangement and disposition of electrodes in it is shown in fig.1. In it is also given an electric (principal) circuit diagram of measuring by the oscillographic method of dual modulation. [4]

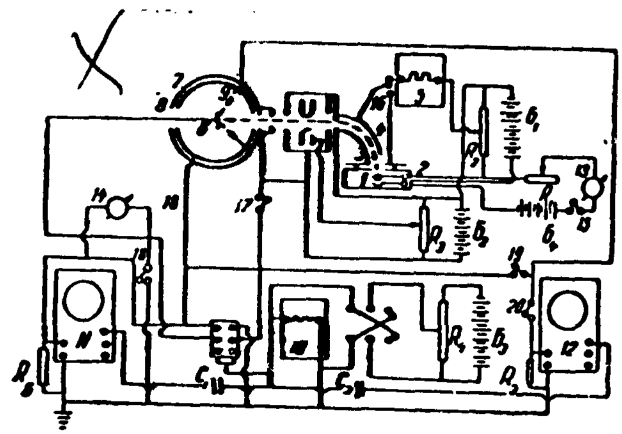

Fig.1.Principal electric circuit diagram of an experimental installation

The beam of positive ions,formed by surface ionization on spiral 1, was extracted by the electric field, applied between spiral and body of source 2. The ion beam, having passed through slot 3 on the body of the source, is separated in the cylindrical condenser 4 from the neutral atoms and molecules and is modulated according to intensity by rectangular pulses generator 5 with a frequency of 500 - 1000 c (first modulation). The ion beam passes then a system of lenses, where it is additionally accelerated and fixed. The beam of primary ions formed in this way and modulated in form of rectangular pulses is directed to target 6, representing a strip of polycrystalline Ta or Mo with a dimension of 1X0.02 X 30 mm^3. The target is surrounded by a collector 7, having cylindrical form, which in turn to be protected against parasitic currents was situated in a protective cylinder 8.

Between the target and collector at a distance of ~1 mm from the internal wall of the collector is placed a movable probe 9 having a dimension of 2 X 8 mm^2. It allows to measure the intensity of secondary ions going from the target under different angles of departure at fixed angle of incidence, and with the aid of a slide it can make a 180° turn in any one direction from the collector slot, intended for entry of a beam of primary ions.

Between target and collector was applied an AC voltage , generated by a generator of sawtooth pulses with a frequency of ~ 25 c (second modulation). Collector and mov-

able probe were collected at the input of vertical amplifiers oscillographs 11 and 12, the horizontal sweeps of which were synchronized by the generator of sawtooth pulses. It is apparent, that each short lived pulse of the primary ion current, depending upon the fact, at which value and voltage sign between the target and collector it reaches the target, it produces a secondary current pulse of various magnitude and direction (ion or electron). These directions are noticed by vertical deviations of oscillograph rays, oscillographs connected to the circuit of the collector and movable probe. Since the frequency of primary ion current pulses is ordinarily selected at many times greater than the frequency of sawtooth pulses, than during the time of changing the voltage between target and collector, or during the time of one sweep we will have a multitude of such pulses in the screens of oscillographs. The envelope of peaks of these pulses represents the dependence of secondary currents upon the voltage between target and collector. The horizontal straight lines, corresponding to positions of oscillographs beams at moments when there is no primary ion current pulse in the target, denote the zero line, separating the values of secondary ions from secondary electron currents. In consequence on the oscillograph screens will be automatically reproduced a stationary volt-amp characteristic of secondary currents.

Secondary currents on the collector and movable probe we measured by oscillograms of volt-ampere characteristics on sections, corresponding to the accelerating voltage of 2-3 v. The application of such a voltage does not distort the picture of angular distribution of secondary currents, because secondary ions possess considerable initial energies. The absence of distortions was checked repeatedly by measuring the current of scattered ions on various sections of volt-ampere characteristic, inclusing also these sections, where there was no voltage between target and collector.

The intensity of secondary ions, abandoning the target at various angles, for various angles of incidence of primary ion beam was measured at various target orientations relative to the direction of the primary ion beam.

With the aid of the movable probe it was possible to very accurately control the possible (especially at greater angle of incidence of primary beam on the target) fly around the target by a beam of primary ions. When the movable probe is shifted behind the target in case of flying arcund the target are observed pulses of primary ions, well distinguishable from pulses of secondary currents by the nature of energy distribution. By good adjustment it was possible not to permit the fly around at angles of incidence of 75° and to these values of angles to investigate the dependence of secondary ion emission upon the angle of incidence of primary ions.

Vacuum in the instrument was produced by a vapor-oil pump and kept at about (2-3) 10^{-6} tores (in working condition). The vapors of oil and lubricants were captured by traps with liquid nitrogen. Prior to measuring the target for subjected for a longer period of time to degasification (2400°K).

Measurements were made at 1350°K after brief heating the target to 2400°K.

It is necessary to mention, that the accuracy of distribution of secondary ions by the angles of departure, obtained with the aid of an arrangement of mentioned dimensions and geometry, is not too high. Recalculations show, that maximum indeterminability of departure angles in directions, reverse or coinciding with the direction of incidence of a beam of primary ions, goes up to 5°.

Measurement Results

Angular distribution of intensity of secondary ions, obtained from oscillograms of volt-ampere characteristics during the bombardment of pure, heated to 1500°K Ta-target with Na-ions with an energy of 300 ev. is shown in fig.2. Here along the axis of the abscissa are plotted angles of departure of secondary ions, and along the axis of the ordinates - current ratios on the movable probe I_3 to the primary ion current I_4 (in any arbitrary scale). The angle of incidence of primary ions $\varphi = 0$, i.e. the beam of primary ionsis directed perpendicularly to the surface of the target. When bombarding a red hot (to 1500°K) Ta-target with Na-ions, as is known [14,15] evaporized and diffusion ions should be very little (not more than 1%).

Consequently secondary ions in the given case appears to be basically scattered and the obtained curve characterizes distribution of intensity by angles only for scattered ions. It is evident from the drawing that the distribution curve of scattered ions coincides practically with the functions graphs cos Θ, i.e. the scattering takes place in accordance with the cosine law.

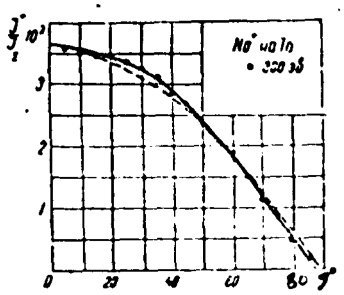

Fig.2. Distribution of intensity of secondary ions over departure angles when bombarding pure, heated to 1500°K tantalum target with Na ions with an energy of 300 ev. The dotted curve corresponds to the theoretical law of cos Θ.

In fig.3. are given the angular dependences of intensity of scattered ions when bombarding pure, heated Ta-target with Na-ions with energies of 300, 600, 800, 1000, 1500 and 1700 ev. As is evident from the drawing with an increase in energy of the bombarding ions the relative number of scattered ions in all directions decreases almost proportionally.

Angular distribution of intensity of secondary Na ions at energies of 300, 600, 800, 1000, 1500 and 1700 ev, reduced to intensity values at an energy of 300 ev, are shown in fig.4. From the arrangement of points and comparing same with curve on graph cos Θ is clear, that the form of the angular distribution of intensity of scattered ions in the mentioned range of energies does essentially not depend upon the energy of the bombarding ions.

Especially investigated was the angular distribution of intensity of scattered ions at various target temperatures. Plotted were distribution curves by angles during the bombardment of a Ta-target with Na-ions, target heated to (1500°K) and cold one after brief conflagration (outburst) (2500°K). The obtained curves for intensity distribution by angles in the investigated range of temperatures (300-1500°K) were not substantially different from each other. Consequently, for a sufficiently pure surface the distribution of intensity of secondary ions by angles does not depend on the temperature of the target.

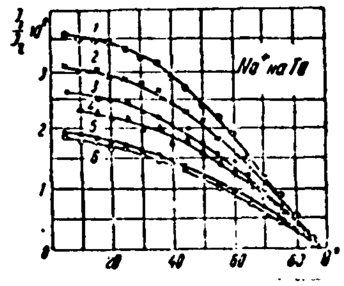

Fig.3. Angular dependences of intensity of secondary scattered ions when bombarding a pure, heated to 1500°K Ta-target with Na-ions with energies: 1-300; 2-600; 3-800; 4-1000; 5-1500 and 6-1700 ev.

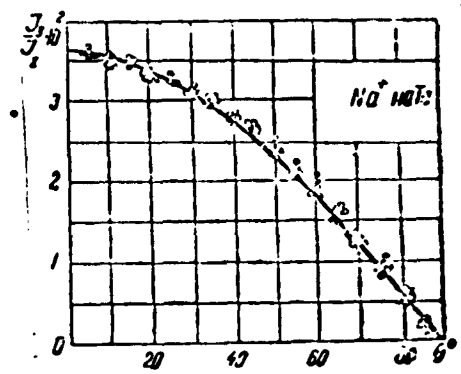

Fig.4. Angular distribution of intensity of secondary ions at energies of primary ions of 300, 600, 800, 1000, 1500, 1700 ev leading to intensity values at energies of 300 ev. The curve corresponds to theoretical law cos θ.

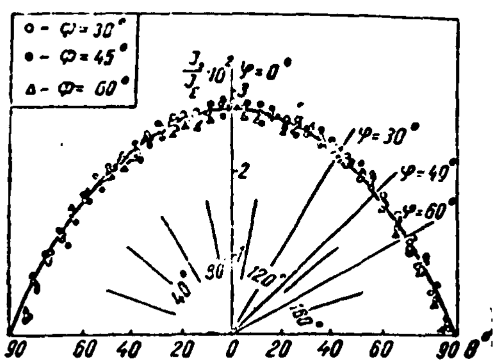

Fig.5. Distribution of secondary ions by departure angles when bombarding heated to 1500°K tantalum target with Na-ions with energy of 900 ev at angles of incidence of primary ions φ =0.39; 45. 60°.

Angular distribution of intensity of secondary scattered ions were also measured at various target orientations relative to the direction of the primary ions falling on the target.

In fig.5 are shown distributions of secondary ions by angles, when bombarding a heated to 1500°K Ta-target with Na-ions with an energy of 900 ev at incidence angles of primary ions φ = 0.45, 60°. Distribution of secondary scattered ions by angles for angles of incidence φ = 45 and 60° coincides with sufficient accuracy with an analogous distribution for normal incidence of primary Na^+ ions on the target. The distribution, coinciding with graph cos θ, as well as in case where φ = 0, when bombarding a target under angle of incidence φ = 45 and 60° was obtained independent from the energy of

the bombarding Na^+ ions and temperature of the Ta-target. Consequently, from the poly crystalline surfaces used by us preferential scattering in mirror or other direction has not been detected.

As already pointed out before, the arrangement of the experimental installation allowed with greater reliability to measure the values of secondary emission coefficients when bombarding a target with ions under various angles of incidence. In fig.6 are given results

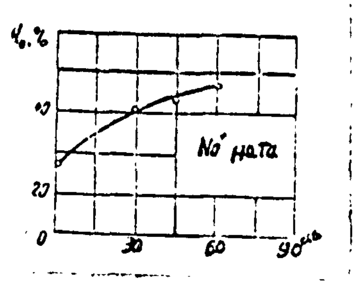

Fig.6. Dependence of the coefficient of secondary ion emission from Ta in relation to angles of incidence of primary Na ions with energies of 550 ev.

of measuring the values of the coefficient of secondary ion emission from Ta in relation to the angle of incidence of primary Na+ ions with energy of 550 ev. Along the axis of the ordinates are plotted the values of secondary ion emission coefficients in percentages, and along the axis of the abscissa - angles of incidence of primary ions on the target in degrees. As is evident from the curve fig.6, the coefficient of secondary ion emission rise with the increase in angle of incidence.

Evaluation of Results

The obtained results do not contradict the ides about the deep nature of reaction of the bombarding ions with individual atoms of the solid body. In the presence of a certain penetration of primary ions into the surface layers of a solid body the yield of scattered ions in direction of the normal to the surface of the target will be maximum. With an increase in the angle of departure, as result of extending the path of motion of scattered ions in the solid body, their yield will decrease. Under greater angles of departure on the collector are falling ions, which experienced scattering basically from the surface atoms of the target. This is quite well evident from distribution of ions by energies, scattered at greater angles. As is known [13] with an increase in the angle of departure the relative number of rapid ions increases.

Such ideas about the scattering of bombarding ions from a solid body are contradicted

even by the presence of a dependence of the value of the secondary emission coefficient K_p upon the angle of incidence of primary ions. As was shown before with an increase in the angle of incidence of primary ions the coefficient of the scattered ions increases. Consequently, when bombarding a target with ions under greater angles of incidence there is a reduction in the depth of penetration of primary ions into the solid body and the yield of scattered ions rises.

Conclusions

1. When the mass of the bombarding ions m_2 is lower than the mass of target atoms m_1, the distribution of scattered ions by angles coincides closely with the cos graph.

2. Distribution of intensity of scattered ion by angles in the investigated range of energies of primary ions under condition when $m_2 < m_1$ does not depend upon the energy of the bombarding ions and temperature of the target.

3. At all angles of incidence of the primary beam on the target the distribution of intensity of scattered ions by angles coincides with cos graph.

4. With the increase in angle of incidence of primary ions the coefficient of secondary scattered ions K_p increases.

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